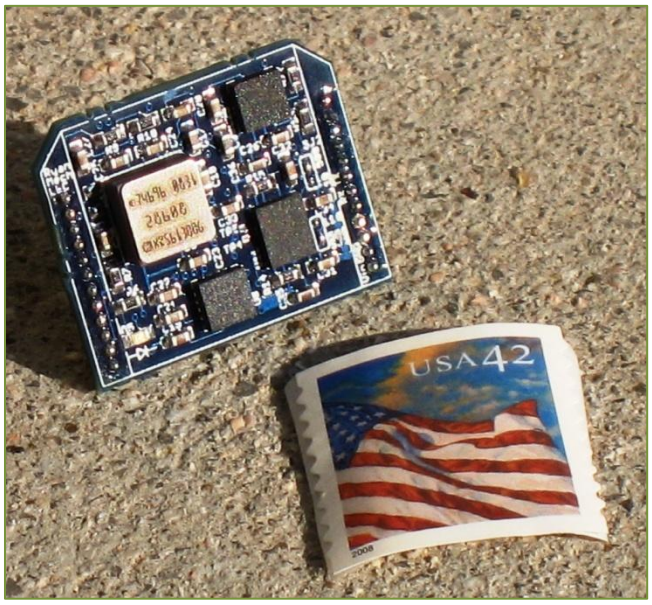
CHIMU Micro AHRS User Manual



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Release Notes

Title	CHIMU		
Subtitle	CHIMU User Manual		
Type	Manual		
Document number	UM1000		
Revision Index	**Date**	**Name**	**Status / Comments**
Initial Release	6/2009	MR	Initial release
A	9/2009	MR	Updates to DAC offsets, message structure
B	10/2009	MR	Updated temperature and bias calibration / save appendices.
C	12/9/09	MR	• Updated CRC information (start value added) • Updated mechanical drawing to show space between pin rows
D	12/28/09	MR	SW Version 1.4 additions include: • Temperature calibration made more robust • Euler angles are now output at 20 Hz update rate even if quaternion estimator is selected • Added user pin select message input (0x12) and output (0x0A) • Added substitute (GPS) heading use message (0x13) to replace magnetometer corrections in high magnetic environments • Noted: Yaw angle reported is True North if magnetic reference vector has been applied, else magnetic north is reported • General text cleanup
D2	3/4/10	MR	Output Message 2, floating point data, had incorrect sequence of values. Previous manual showed accel, mags, then rate. Actual software has always been accel, rate, mags. Documentation updated only.
D3	3/8/10	MR	Pin 17 and 18 were incorrectly swapped in the documentation. Pin 17 was incorrectly called out as the analog input. Pin 18 is the analog input pin for speed if using that for centripetal calculations (vs. software messages). Fixed in this revision (documentation change only)

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1. Introduction

The CHIMU is a miniature, low cost Attitude Heading Reference System (AHRS). AHRS units employ rate, acceleration, and magnetic sensing to provide a full inertial attitude and heading estimate, even under stationary conditions. The CHIMU is intended for use in motion sensing applications including, but not limited to:

- UAVs (AUVs, UAS, etc)
- Robotics
- Sports training and analysis
- Education
- Rocket science

1.1 Limitations

The unit, like any IMU / AHRS, can be pushed beyond the limits of its ability to sense any of the measurements it needs to operate correctly. The following list includes results that are known to occur if operation exceeds the limits listed later in this document.

1.1.1 Rate limits

Saturation of maximum rate in any axis for any amount of time will result in an incorrect attitude estimate. The longer the saturation duration, the more error will be present in the attitude determination. The attitude estimate shall recover once saturation has stopped and the internal filter has time to reconverge on the correct solution.

1.1.2 Acceleration limits

Excessive acceleration can include acceleration above the rated levels in continuous application (static / low frequency g's), more elusive vibration (sinusoidal / random) or shock (impulse / random) events that may not show full saturation of the accelerometers in data output, but have affected the sensors internally and corrupted the values. Continued acceleration above the limits or excessive vibration / shock events can corrupt the computation of rate sensor biases, leading to poor bias estimates and a corrupt attitude estimate.

1.1.3 Magnetic field limits

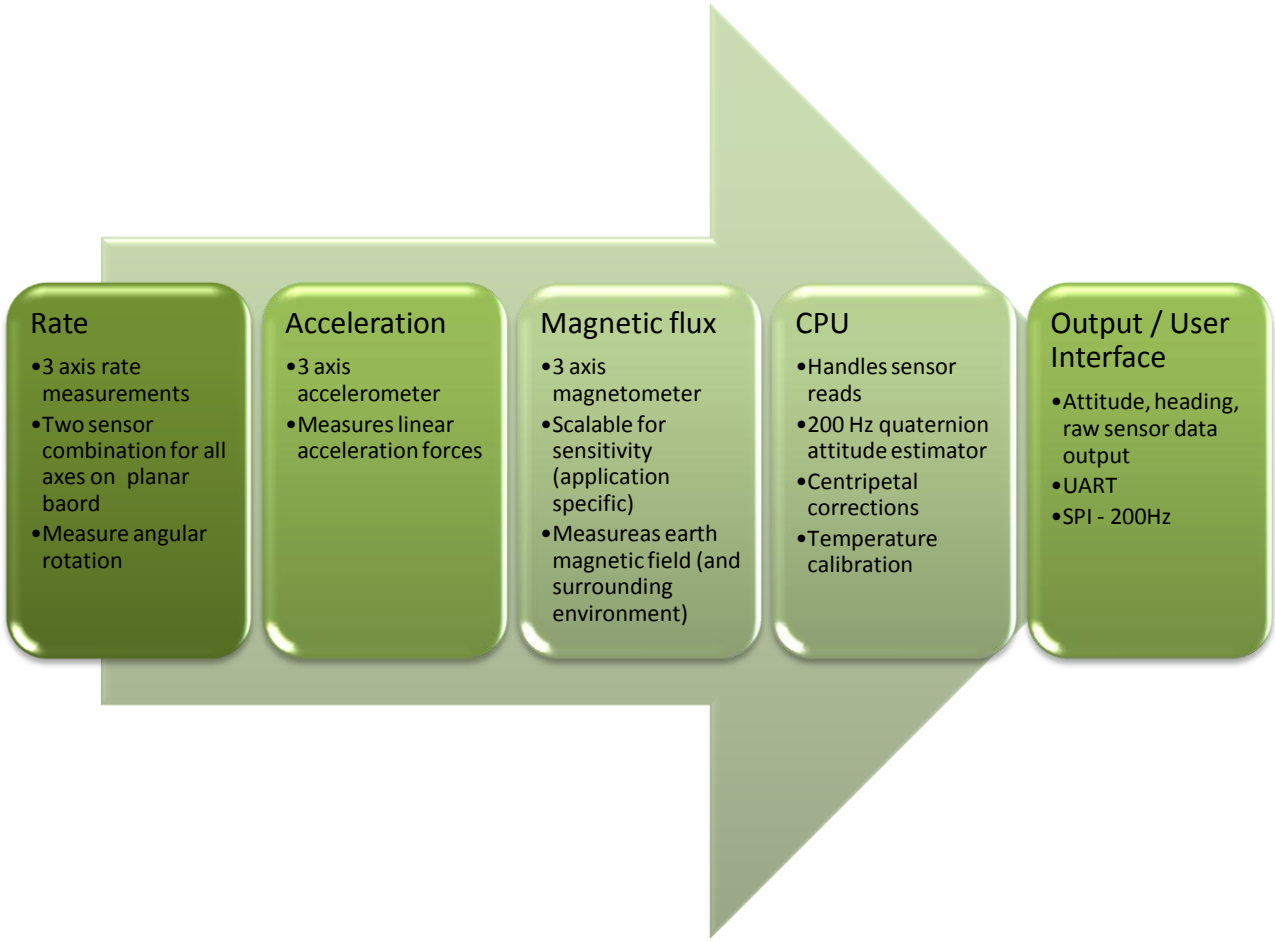
Saturation of the local magnetic field can result in a pervasive attitude estimate error as well. Calibration of the unit in the final configuration will help prevent errors introduced by hard iron in the local area. However, induced magnetic fields from high current devices or high power RF circuitry can result in operational errors. After a proper calibration, no axis should exceed a +/- 1 value.

1.1.4 BIT and User Responsibility

Automatic sensing of limits being exceeded is difficult. However, the CHIMU does have some internal capability to discern these conditions. Magnetic sensor saturation is reported in the Built In Test (BIT) message. Future software revisions may include an indication of saturation or other errors on other sensors. No system is fool proof however, and all correct use and planning for events in case of failure are the responsibility of the user.

1.2 Theory of Operation

The CHIMU is an integrated set of MEMS sensors that are managed via an onboard CPU to provide attitude and heading information, along with raw sensor data and other useful information. A top level flow of the primary components are shown in this figure:



1.2.1 Startup Conditions

The most difficult operation for a MEMS based IMU to perform occurs at turn on. In order to provide a fast, reliable estimate of attitude, some systems require the unit to be held motionless during turn on. This is to provide a “zero” for immediate calibration.

The CHIMU does not require this turn on requirement if it has been calibrated over temperature. Static calibration values across the operating temperature range are preprogrammed prior to delivery (or are calibrated / recalibrated after delivery if necessary). In-run biases for the unit sensors are calculated as part of the internal processing after turn on, and compensate for minor changes that may have occurred over time from factory defaults and operational conditions.

1.2.2 Dynamic Operation – Centripetal Acceleration

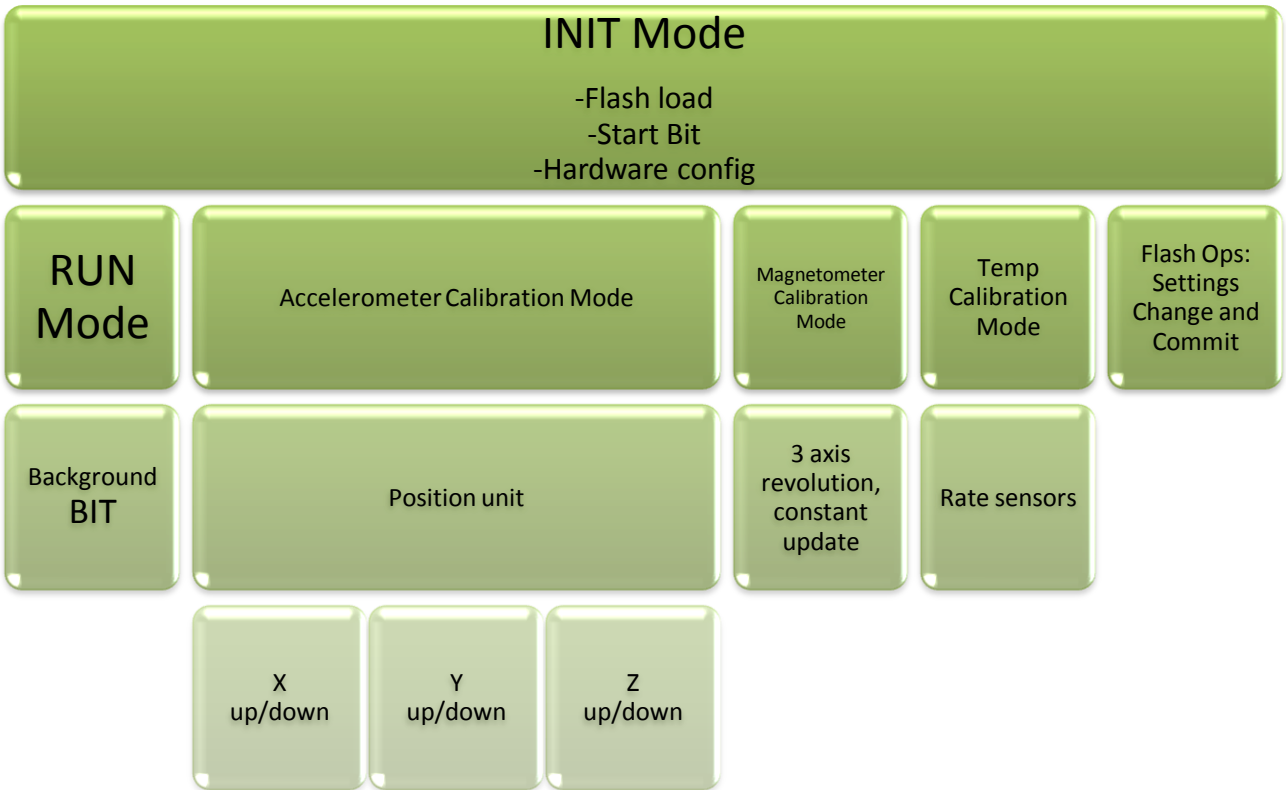
Operation of an IMU in a dynamic platform like an airplane can lead to incorrect attitude computations unless centripetal accelerations are accounted for. Many low cost MEMs based IMUs do not address this.

The CHIMU allows two methods for compensation of centripetal accelerations. Both require an external input of vehicle velocity. The first, and most useful for many applications, is an external pin that allows input of forward speed as an analog voltage. The second requires a full 3 axis velocity message to be provided to the unit via the serial port or SPI port.

External computation of velocity can be provided by airspeed sensors or a GPS unit (typically).

1.3 Modes of Operation

The CHIMU has been designed to be simple and effective at providing attitude and heading information with minimal or no user intervention. However, there are some modes for calibration that likely will be used. Below is a top level description of the typical operating modes for the unit. This diagram may be useful in understanding the software commands to the module found in this section.



2. Specifications and Characteristics

Presented in this section are the sensor and system specifications for the CHIMU. All parameters specified are @ VDD = 3.0 V and Ta = 25°C.

2.1 Performance Specifications

Characteristics	Conditions	Min	Typical	Max	Units
Attitude and Heading (steady state)					
Roll Range Accuracy Resolution			 0 to 360 1 0.0004		 ° ° RMS °
Pitch Range Accuracy Resolution			 +/-90 1 0.0004		 ° ° RMS °
Yaw Range Accuracy Resolution			 0 to 360 1 0.0004		 ° ° RMS °
Angular Rate					
Range	Pitch, Roll Yaw		±500 ±150		° / sec
Rate noise density	Pitch, Roll Yaw		0.05 0.04		° /sec / $\sqrt{Hz}$
Bandwidth	Pitch, Roll Yaw		140 200		Hz
Resolution	Pitch, Roll Yaw		<±0.24 <±0.07		 ° / sec
Acceleration					
Range	All axes	±3	±3.6		g
Noise density	X / Y Z		280 350		$ug/\sqrt{Hz}\ RMS$
Bandwidth	All		50		Hz
Resolution	All		<±1.8		mg
Magnetic Flux					
Range	All axes		±1		Gauss
Bandwidth	All		10,000		Hz
Resolution	All		7		milligauss

- Specifications are subject to change at any time without notice

2.2 Electrical Characteristics

Characteristics	Conditions	Min	Typical	Max	Units
Power					
Supply Voltage Range	V_{dd} Referenced to GND	3.1	3.3	6.5	V
Current	Average, measured at 3.3V	30	40	50	mA
Time					
Time to first valid data	Power on to first message out		0.1		sec
Bias settling time	Static test step change condition		<20		sec

- Specifications are subject to change at any time without notice

2.3 Absolute Maximum Ratings

Parameter	Rating
Acceleration (any axis, 0.5 ms) Unpowered	2000g
V_{dd}	-0.3V to +7V
Output Short-Circuit Duration (Any Pin to Common)	TBD
Operating Temperature Range	-30°C to +85°C
Storage Temperature Range	-40°C to +125°C

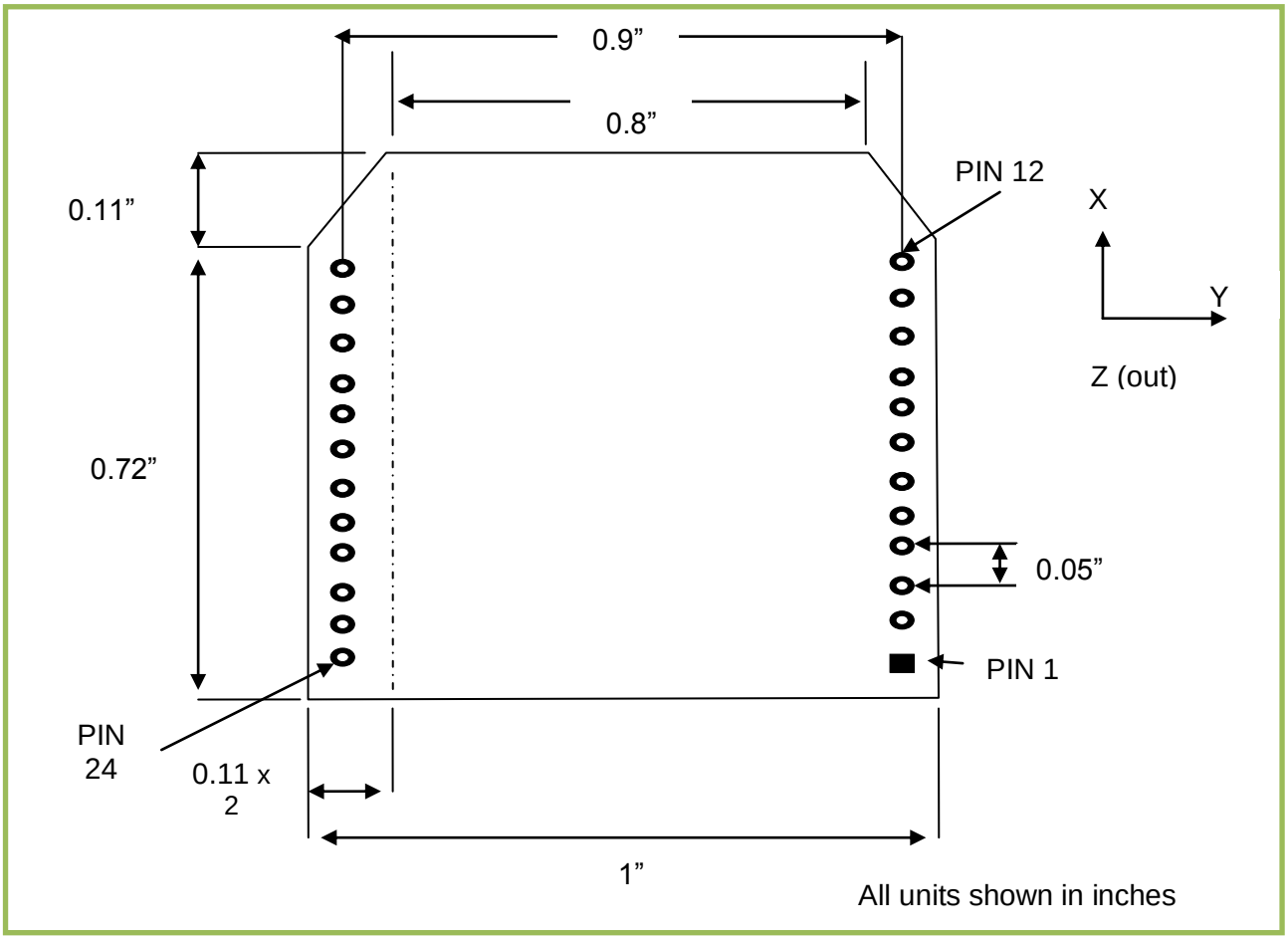
- Specifications are subject to change at any time without notice

Stresses above those listed under the Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at or near these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect device reliability.

Drops onto hard surfaces can cause shocks of greater than 2000 *g* and can exceed the absolute maximum rating of the device. Exercise care during handling to avoid damage.

2.4 Mechanical and Pin Assignments

2.4.1 Dimensions



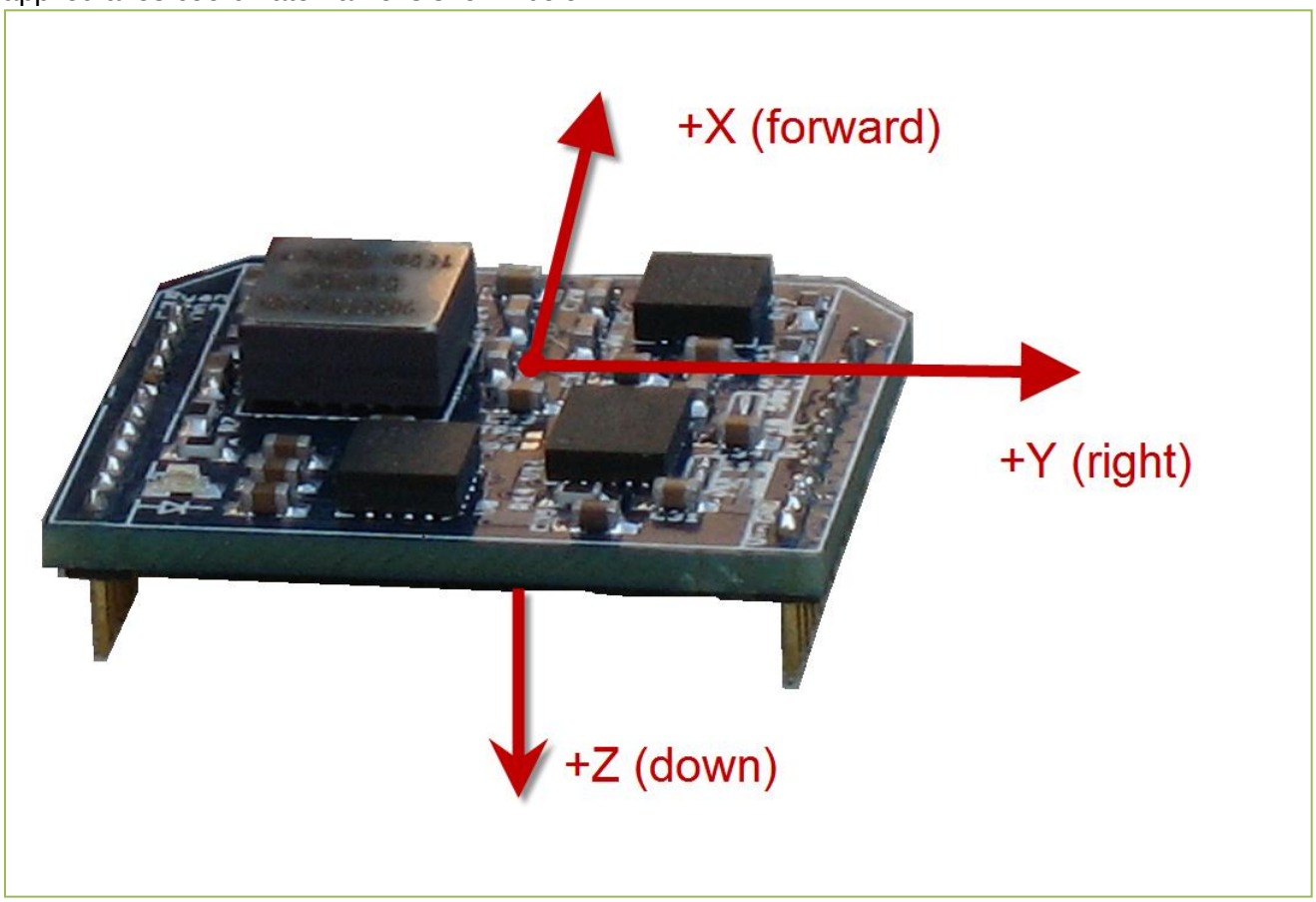
2.4.2 Recommended Connectors

The connectors on the CHIMU have a 0.05” spacing. Specifically, the CHIMU pins are Digi-Key part number S9014E-12-ND.

The recommended mate (socket) that custom designs should use to plug CHIMU into is Digi-Key part number S9005E-12-ND. For reference, a picture of this connector is shown here:

2.4.3 Coordinate System and Orientation

Orientation shown (X/Y/Z) frame is the local body frame, using standard aircraft axes. The unit with applied axes coordinate frame is shown below.



It is assumed for the rest of this manual that this axis corresponds to a standard vehicle axis. All rotations obey the "right hand rule". In this case, the following terms are defined:

- Pitch rate / angle ($\dot{\theta}$, θ) – positive pitch rate is rotation about the Y axis from the Z towards the X axis.
- Roll rate / angle ($\dot{\Phi}$, Φ) – positive roll rate is rotation about the X axis from the Y to the Z axis.
- Yaw rate / angle ($\dot{\Psi}$, Ψ) – positive rate is rotation in a clockwise direction about the Z axis from the X to the Y axis.

2.4.4 Pin Assignments

Table 1 - Pin Assignments

Pin #	Pin Name	I/O	Pin Connection Required for Typical Operation?	Description
1	Vin	N/A	X	Input power
2	GND	N/A	X	
3	DIO_1	I		External Speed Sensor enable (ground pin if external analog speed sensor available)
4	NSS	I		COM Select
5	MOSI	O		SPI – Master Out Slave In
6	SENSOR RX	I		UART com TO CHIMU 3.3V level
7	SENSOR TX	O	X	UART com FROM CHIMU 3.3V level
8	MISO	I		SPI – Master In Slave Out
9	SCK	O		SPI – Clock
10	GND	N/A	X	
11	RATE0	O		Special – compensated output of pitch axis rate or angle (software selected, default rate)
12	RATE1	O		Special –compensated output of roll axis rate or angle (software selected, default rate)
13	NC	N/A		No function
14	SCL	O		Internal I^2C Clock – Do Not Connect
15	SDA	O		Internal I^2C Data – Do Not Connect
16	GND	N/A	X	
17	ANA2	I		Defines Angle or Rate mode output from pins 11/12. Leave unconnected for rate mode. Connect to ground for angle mode.
18	ANA1	I		X axis velocity input Enabled by Pin 3
19	GND	N/A	X	
20	DIO_2	I		User Option select pin (SW version 1.4 and higher)
21	GND	N/A	X	
22	PRG	I		Programming use – do not connect
23	RST/C2CK	I		Soft reset – active low reset holds CPU in reset
24	3.3V Out	O		Limited 3.3V supply (50mA max)

3. Hardware Integration

Presented in this section are selected hardware interface comments to help ease integration of the unit in the end user system.

3.1 Power

3.1.1 Input Power

The CHIMU module operates off a nominal 3.3V input. However, up to 6.5V may be applied. A higher voltage may result in more thermal dissipation on the board, but this should not affect operation. Do not exceed 6.5V or damage may result.

The system draws very little power; typically it will require 30 mA of supply for operation. More will be required if the output power pin is used.

If the 3.3V output pin is used to power external devices, then the input power current will need to be increased to support this additional use.

3.1.2 Output Power

The module outputs 3.3V from its onboard regulator on pin 24. This is not intended to be used to drive any high current or critical loads, but may be useful for pull up / down or LED operation. Total current from this output should be limited to less than 50mA. More than this risks interfering with operation of the unit.

3.2 Special Interface Pins

The CHIMU utilizes external pins to help configure the unit if software interfacing is not possible. These pins are described here.

3.2.1 External Speed Select – Pin 3 – DIO_1

Pin 3 indicates to the unit that the external voltage on Pin 18 (ANA1) should be treated as the forward (X) velocity indicator.

- High / not connected
  - No external hardware speed input
  - DO NOT EXCEED 3.3 VOLTS ON THIS PIN
- Low / Grounded
  - Pin 18 (ANA1) acts as a direct indicator of forward (+X) velocity according to the bias and scale factor associated with this input
  - Scale ranges from 0 to 2.5V
  - Standard bias and scale factor result in a linear scale of:
    - 0 V = 0 m/s
    - 2.5V = 66 m/s (147 mph)

3.2.2 Com Select – Pin 4 - NSS

Pin 4 indicates to the unit which communication structure should be used. Currently, SPI communication is only as a master device. This pin is reserved for future use in an SPI slave configuration.

3.2.3 Special – Pin 11 – RATE0

This pin requires special external circuitry to be useful. As a default, this pin outputs current proportional to the current pitch attitude of the unit. Direct rate output can be achieved via setup thru the serial port.

The output from this pin is NOT A VOLTAGE. External interface boards that provide useable voltages from this pin are available. Please contact us for more information before attempting to interface to this pin.

3.2.4 Special – Pin 12 – RATE1

This pin requires special external circuitry to be useful. The pin outputs current proportional to the current roll attitude of the unit. Direct rate output can be achieved via setup thru the serial port.

The output from this pin is NOT A VOLTAGE. External interface boards that provide useable voltages from this pin are available. Please contact us for more information before attempting to interface to this pin.

3.2.5 Speed Indicator – Pin 18 – ANA1

Described previously, this pin (when enabled by Pin 3) will accept a voltage in the range of 0 to 2.5V to represent a forward speed of 0 to 66 m/s to allow centripetal corrections.

This pin may be interfaced (with proper scaling) directly to a pitot tube airspeed sensor output for example.

If more complex velocities are present, or if a hardware interface is not desired, then software input of the vehicle velocity should be used. For aircraft, a forward speed indicator should be sufficient for most applications.

3.2.6 Angle / Rate Output Selection – Pin 17 – ANA2

This pin when left high allows scaled and corrected rate outputs from pins 11 and 12. If this pin is grounded, then the angle output mode for these pins will be selected.

Currently, if the angle output mode is selected, then the Euler estimator will engage automatically to ensure angle output is compatible with expected definitions.

3.2.7 User Option Select – Pin 20 – DIO_2

Enabled in SW version 1.4 and higher, this pin activates different features on the CHIMU unit when pulled low. Those features are enabled via a special software message. The default activity on this pin is nothing (i.e. no effect).

- Custom designs should provide a breakout for this pin in case future functions prove useful.

3.3 Communication

The CHIMU has two means of communication - a standard UART and an SPI port.

3.3.1 UART

The UART is a 3.3V level interface. The unit does not use hardware handshaking. It is always 8 bits, no parity, and one stop bit (8-N-1). Do NOT interface with a standard RS-232 port, as the

voltages on that port will damage the unit. An external adapter that uses 3.3V to convert to RS-232 levels can be powered from the onboard 3.3V regulator.

Standard operation is at 115k baud with a message output rate of 25Hz. Currently, this is a fixed baud rate. However, the data output rate can be varied from 0 to 50Hz and a message mask allows selective output of data.

3.3.2 SPI Bus

The SPI bus is configured as a master device. The SPI bus outputs all data at the full 200Hz data rate. Further details, including C source code for interfacing to this bus and receiving data, is available upon request from customers.

3.4 Feedback LED

There is one (1) informational LED on the unit. This LED is for information only, and is not necessary to view during operation. The LED operation is as follows:

- Boot / Initialize – Solid on
- Normal operation – toggling of on/off at 1/10th the UART interface output rate
- Failed operation in use – Solid on or solid off

4. Software Interface

The CHIMU hardware com interfaces have been described already. Details on software setup and communication are presented here.

4.1 Basic Message Structure

Input and Output messages from the unit are identical. Both include header and checksum and other information to protect data integrity and allow easier decoding by the end user.

4.1.1 Message format

Both input and output messages have a defined structure that consists of the following:

- (2) header bytes (0xAE 0xAE)
- (1) Message length byte – one byte representing the payload length only (i.e. no header, length, device id, message id or checksum included)
- (1) Device ID byte (useful when multiple units are used in a single application)
- (1) Message ID byte
- (xxx) Data bytes (varies with message)
- (1) Checksum byte

The checksum byte is the LSB of a 32 bit CRC checksum calculated for the entire message, including header bytes, length, id, and data bytes. Details and code for calculating this checksum are provided later in this section.

4.1.2 Number Formats

Much of the data messages use single bytes and unsigned integers, which are typically easy to understand. A number format list is presented here for clarity on number formats however.

All multi-byte values are ordered in Big Endian format, unless otherwise indicated.

NOTE: Most PC's (Intel) are Little Endian oriented. This needs to be taken into consideration if interfacing directly to the device with custom software.

All floating point values are transmitted in IEEE754 single precision.

Table 2 - Number Formats

Abbreviation	Type	Size (bytes)	Comment	Min/Max
U1	Unsigned char	1		0 … 255
I1	Signed char	1	2's complement	-128 … 127
X1	Bitfield	1		n/a
U2	Unsigned short integer	2		0 … 65535
I2	Signed short integer	2	2's complement	-32768 … 32767
X2	Bitfield	2		n/a
U4	Unsigned long	4		0…4,294,967,295
L4	Signed long	4	2's complement	-2,147,483,648 … 2,147,483,647
R4	IEEE 754 Single Precision	4		-1*2^127 … 2^127
CH	ASCII encoded	1		

4.1.3 CRC Checksum Code

The checksum calculated for outgoing messages is a 32 bit CRC code. C code to compute the entire checksum is shown below.

Important notes:

1) Only the **LSB** of this CRC is appended to output message

2) The starting polynomial is **0xFFFFFFFF**

```
#define POLY 0xEDB88320 // bit-reversed version of the poly 0x04C11DB7

unsigned long UpdateCRC (unsigned long CRC_acc, unsigned char CRC_input)
{
        unsigned char i; // loop counter
        // Create the CRC "dividend" for polynomial arithmetic (binary arithmetic
        // with no carries)
        CRC_acc = CRC_acc ^ CRC_input;
        // "Divide" the poly into the dividend using CRC XOR subtraction
        // CRC_acc holds the "remainder" of each divide
        //
        // Only complete this division for 8 bits since input is 1 byte
        for (i = 0; i < 8; i++)
        {
                // Check if the MSB is set (if MSB is 1, then the POLY can "divide"
                // into the "dividend")
                if ((CRC_acc & 0x00000001) == 0x00000001)
                {
                        // if so, shift the CRC value, and XOR "subtract" the poly
                        CRC_acc = CRC_acc >> 1;
                        CRC_acc ^= POLY;
                }
                else
                {
                        // if not, just shift the CRC value
                        CRC_acc = CRC_acc >> 1;
                }
        }
        // Return the final remainder (CRC value)
        return CRC_acc;
}
```

5. Input Message Details

Shown in this section are specific input message requirements and details

5.1 Input Message – Device ID IS Required!

The unit shall not respond to requests that do not contain its device ID. The default factory value for the device ID is 0x01, but can be changed by the user. **The broadcast device ID of 0xAA will force any units listening to accept the messages sent.**

5.2 Input Message Summary

The output messages from the unit are shown in this summary table:

Table 3. CHIMU Message Input

Name	ID	Length	Description
Ping	0x00	0	Communication check
Bias and Scale Factor	0x01	67	Sets bias and scale factor values
DAC Mode	0x02	6	Sets the output mode from rate to angle on pins 11 and 12
Accelerometer Calibration	0x03	1	Calibrates accelerometers
Magnetometer Calibration	0x04	1	Calibrates magnetometers
Temperature Calibration	0x05	1	Temperature calibration of rate sensors
Configuration CLEAR	0x06	1	Clears configuration flash memory
Configuration SET	0x07	2	Saves current configuration to flash memory
Gyro Bias Save	0x08	1	Saves current rate sensor biases as power up defaults. This is in addition to temperature calibration values for bias.
Estimator Type	0x09	1	Attitude estimator selection (quaternion or Euler) (default = 1, quaternion)
Gyro SF Check	0x0A	1	Special – integrates gyros only to check scale factor
Centripetal Velocity	0x0B	13	Allows input of vehicle velocity vector to account for centripetal acceleration
Initialize Gyros	0x0C	0	Sets current value for rate sensors as zero point
Device ID Change	0x0D	2	Sets new device ID
Magnetic Reference Vector	0x0E	21	Sets new magnetic reference vector and declination / inclination for local area
Reset	0x0F	1	Performs a software reset of the unit
UART Rate and Mask Settings	0x10	6	Sets the output rate and message mask on the UART.
Reserved	0x11	-	-
User Pin Option Select	0x12	6	Sets options enabled by Pin 20 use
GPS / Substitute Heading	0x13	5	Allows override (in Euler estimator) of internal yaw reference source.

5.2.1 PING (ID 0x00)

Description	**PING**
ID	**0x00**
Length	**1**
Type	Input Message
Comment	**Pings the unit. Unit responds with ping output message, BIT message, and user requested message. Useful for software protocol test.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x00	None	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Requested Message	-	Requests a specific output message

This message forces a ping output message (0x00) and a BIT message (0x05) as a response regardless of the package data.

The message indicated by the package byte (other than 0x00 or 0x05) will be output as well.

5.2.2 BIAS AND SCALEFACTOR (ID 0x01)

Description	**BIAS AND SCALE FACTOR**
ID	**0x01**
Length	**67**
Type	Input Message
Comment	**Changes bias / scale factor**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	67	*id* or 0xAA	0x01	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Read / Write	-	Requests a read or specifies a write of data
1	I2	-	Temp Sensor Bias	-	Do not change
3,5,7	I2	-	Accel X, Y, Z bias	m/s^2	Note: 3 integers, one for each axis
9,11,13	I2	-	Rate Sensor bias	Rad/s	""
15, 17, 19	I2	-	Magnetometer bias	Local gauss (normalized)	""
21	I2	-	Hardware analog 1 read (velocity input) bias		
23			Temp Sensor SF	-	
27,31,35	R4	-	Accel X, Y, Z SF	m/s^2	Note: 3 floating point values, one for each axis
39,43,47	R4	-	Rate Sensor SF	Rad/s	""
51,55,59	R4	-	Magnetometer SF	Local gauss (normalized)	""
63	R4	-	Hardware analog 1 read (velocity input) SF		Scale as needed for external hardware speed input.

Typically, these settings are not altered via this message. Calibration of the unit stores these values automatically. However, advanced users may wish to save configurations and write them for experimental reasons.

5.2.3 DAC MODE (ID 0x02)

Description	**DAC Mode**
ID	**0x02**
Length	**4**
Type	Input Message
Comment	**Changes DAC output mode and allows offset changes**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	6	*id* or 0xAA	0x02	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Rate / Angle	-	1 = angle output from DAC channels 0 = angle output
1	U1	-	Read / write / save	-	0 = requests a DAC offset message 1 = writes the offsets until the next power cycle 2 = commits them to flash memory (i.e. permanent)
2	U2	-	Offset channel 0	-	Counts for ADC (0 to 4095) offset to the Pitch channel
4	U2	-	Offset channel 1	-	Counts for ADC (0 to 4095) offset to the Roll channel

5.2.4 ACCELEROMETER CALIBRATION MODE (ID 0x03)

Description	**Accelerometer Calibration Mode / Selection**
ID	**0x03**
Length	**1**
Type	Input Message
Comment	**Enters / designates unit orientation for calibration of accelerometers**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x03	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Position	-	0 = level (x, y = 0; z = -1) 1 = upside down (x, y = 0; z = 1) 2 = up (x = 1, y, z = 0) 3 = nose down (x = -1, y, z =0) 4 = right wing up (x = 0, y = +1, z = 0) 5 = right wing down (x = 0, y=-1, z =0)

To start the calibration process, the level (0) position must be sent first.
To finish the calibration, the right wing down (5) position must be sent last.

Recommended use if needed:

- Enter calibration with unit level command
- Progress thru all 5 remaining positions sending required command at each position
- Final position results in bias and scale factor being saved to flash memory.

Any position other than 5 may be sent during calibration and the new value shall be recorded in place of the last one.

Keep the unit motionless during the command to prevent erroneous acceleration from entering the calibration process.

5.2.5 MAGNETOMETER CALIBRATION MODE (ID 0x04)

Description	**Magnetometer Calibration Mode**
ID	**0x04**
Length	**1**
Type	Input Message
Comment	**Enters / exits unit orientation for calibration of magnetometer**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x04	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Action	-	0 = Enter magnetometer calibration mode 1 = exit mode

To start the calibration process, the Enter (0) command must be sent. The unit should be rotated continuously, pointing every axis at the north vector (magnetic north for you location).
Exit the calibration process by sending a (1) in the payload.

Do not have high current or ferrous metal near the unit (within 1 foot) during calibration unless it is part of the normal operating condition.

5.2.6 TEMPERATURE CALIBRATION MODE (ID 0x05)

Description	**Temperature Calibration Mode**
ID	**0x05**
Length	**1**
Type	Input Message
Comment	**Enters / exits temperature calibration of unit. Not typically needed, done at factory.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x05	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Action	-	0 = Enter temp cal mode 1 = exit mode

To start the calibration process, the “Enter” (0) command must be sent. The unit should be kept completely motionless at a cooled temperature initially, then allow the unit to slowly warm to a higher temperature.

At least 30 degrees of temperature change from start to finish should be experienced for best results.

Results are saved to flash memory automatically at the exit of the mode.

Please see the appendix for more information.

5.2.7 CONFIGURATION CLEAR (ID 0x06)

Description	**Configuration Clear**
ID	**0x06**
Length	**1**
Type	Input Message
Comment	**Clears all saved flash and returns unit to defaults after power cycle**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x06	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Action	-	0xAB = clears flash All other values have no effect

5.2.8 CONFIGURATION SET (ID 0x07)

Description	**Configuration Set**
ID	**0x07**
Length	**1**
Type	Input Message
Comment	**Sets current configuration with option to save it to flash memory**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	2	*id* or 0xAA	0x07	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Action	-	0xAB = saves to flash memory for subsequent use. All other values have no effect in this field.
1	X1	-	Bit field settings	-	See bit settings and meanings below

This message allows certain configuration settings to be set and saved to flash if required. The configuration settings can be set without saving to flash also to test the settings. Flash save will only occur if 0xAB is written as the first byte in the payload.

The bits in the configuration status that can be altered directly in the second package byte are as follows:

bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Allow Hardware Pin Config Override (default = 1, allow)	X	X	X	Rate Out / Angle Out Configuration (default = 1, rate out)	Temperature Calibration Start / Stop (default = 0, do not use)	Hardware Centripetal Velocity Enable (default = 1, enabled)	SPI Enable Override (default = 1, enabled)

Note that the current estimator type bit 4 cannot be altered by this message. However, if this message is saved to flash, then the current estimator type will be saved as well.

In this manner, the default estimator that runs on power up may be changed. Message 0x09 should be used to change the estimator type.

5.2.9 GYRO BIAS SAVE (ID 0x08)

Description	**GYRO BIAS SAVE**
ID	**0x08**
Length	**1**
Type	Input Message
Comment	**Saves rate sensor biases**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x08	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Clear / Save	-	0 = clear 1 = save current values to flash

This message allows the setting or clearing of rate sensor bias values in flash memory. This is in addition to temperature calibration, as it reflects biases added after in run operation.

Only save these values if the unit has been motionless for 10 minutes or more under relatively steady state temperature conditions for best results.

Please see the appendix for more information.

5.2.10 ESTIMATOR TYPE SET (ID 0x09)

Description	**Estimator Type Set**
ID	**0x09**
Length	**1**
Type	Input Message
Comment	**Sets estimator type from quaternion based to Euler or vice versa. Future versions of software may have different estimator types.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	2	*id* or 0xAA	0x09	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Estimator type	-	0 = Euler estimator 1 = Quaternion estimator

This message allows the internal estimator type to be set. This can be saved to flash for subsequent boots with the configuration set command (0x07). The differences between the two are shown below:

Estimator type

Estimator Type	**Pros**	**Cons**
Quaternion	• No singularity points in the attitude determination • Quaternion output can be used directly in navigation and other rotation calculations	• User must decode / interpret quaternion output correctly for use in external code
Euler	• Standard roll, pitch, yaw output easy to visualize	• Subject to “gimbal lock” singularity at +/- 90 degrees pitch orientation.

Further information about quaternion versus Euler configuration and the technical background behind the two estimators can be found in Appendix A: Quaternion vs. Euler Estimator.

5.2.11 GYRO SCALE FACTOR CHECK (ID 0x0A)

Description	**Gyro Scale Factor Check**
ID	**0x0A**
Length	**1**
Type	Input Message
Comment	**Used to check / verify scale factor for rate sensors**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x0A	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	SF Check start / stop	-	0 = Stop 1 = Start

When this command is sent as a start, the unit begins doing a direct integration on all three rate sensors and reporting the resultant angle via message 0x0F (15).

A typical example of using this message is to engage the operation, rotate the unit a fixed angular amount, and then check that the integrated angle meets it within some tolerance.

Note that biases are not removed from the sensors before they are integrated; it is left to the user to account for this if using this message.

5.2.12 CENTRIPETAL VELOCITY INPUT (ID 0x0B)

Description	**Centripetal Velocity**
ID	**0x0B**
Length	**13**
Type	Input Message
Comment	**Allows input of vehicle velocity vector to account for centripetal acceleration**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	13	*id* or 0xAA	0x0B	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	X1	-	Centripetal configuration	-	0 = All OFF 1 = HW Centripetal Enable 2 = SW Centripetal Enable
1	R4	-	Vehicle X velocity	m/s	Forward velocity
5	R4	-	Y velocity	m/s	
9	R4	-	Z velocity	m/s	

A vehicles velocity while rotating (i.e. a plane changing course with a rudder has a forward X velocity and a yaw rate) can induce centripetal accelerations that must be compensated for in order to maintain an accurate attitude estimate.

The CHIMU allows an external X velocity input via a hardware analog channel. That channel can be enabled via a secondary pin. This message allows (byte 0 = 0x01) enabling of that channel without needing to pull that enable pin low. In this case, only the external ADC read will be used, and it is assumed to represent the forward (X) velocity.

This message also allows (byte 0 = 0x02) a full velocity vector input to use, including X, Y, and Z velocity vectors.

Warning: The last velocity sent stays active until changed or this capability is turned off! Make sure that constant updates are provided if using this function, or that it is disabled in low velocity or near static conditions or erroneous attitude estimates will result.

5.2.13 GYRO INITIALIZATION (ID 0x0C)

Description	**Gyro Init**
ID	**0x0C**
Length	**0**
Type	Input Message
Comment	**Allows snapshot of current rate sensor values as bias**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	0	*id* or 0xAA	0x0C	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description

There is no payload for this message. When sent, the current rate sensor readings are used as the new “zero rate” points, overriding the current biases.

If a unit has been temperature calibrated, this message will overwrite those values.

If a unit has not, then this action occurs at boot.

The unit should be static during this event, or a false zero set point will be set.

5.2.14 DEVICE ID (ID 0x0D)

Description	**Device ID change**
ID	**0x0D**
Length	**2**
Type	Input Message
Comment	**Allows change of unit device ID. If save flag is set to 1, unit saves ID to flash memory. 0xAA is a generic broadcast ID if ID is unknown, and should be used to set new ID.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	2	*id* or 0xAA	0x0D	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Device ID	-	Desired device ID
1	U1	-	Save / No Save	-	1 = save to flash 0 = do not save

This message changes the device ID to the specified value. If unsure of current device ID, use 0xAA. If using on a network with multiple units be careful…0xAA as device ID will change all units to the new ID.

5.2.15 MAGNETIC REFERENCE VECTOR (ID 0x0E)

Description	**Reference Vector**
ID	**0x0E**
Length	**21**
Type	Input Message
Comment	**Allows set of local magnetic reference vector (declination / inclination) for accurate heading determination**

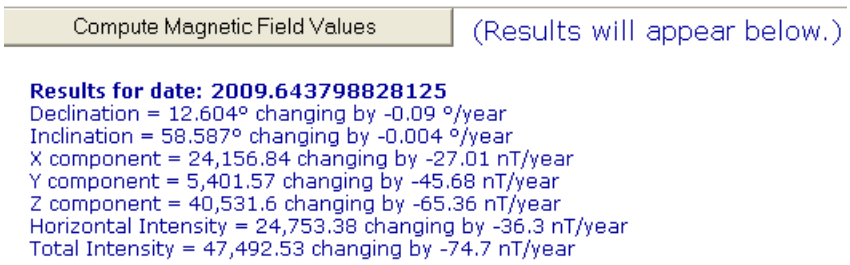
Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	21	*id* or 0xAA	0x0E	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	X1	-	Read / write / save	-	0 = Request a read message (0x0E, 14) output 1 = Write new vector 2 = Write and save new vector to flash
1	R4	-	Ref Vector X	Unit vector component	Magnetic reference UNIT vector in ECEF X direction
5	R4	-	Ref Vector Y	Unit vector component	Y
9	R4	-	Ref Vector Z	Unit vector component	Z
13	R4	-	Inclination	rad	Local inclination of magnetic field
17	R4	-	Declination	rad	Local declination of magnetic field

In order for accurate heading information to be developed, the local magnetic field needs to be input into the unit. To find local inclination and declination values for your area, use your zip code or lat / long at this site:

http://www.ngdc.noaa.gov/geomagmodels/IGRF.jsp

Have the site compute your local values and you will see a message similar to this:


Compute Magnetic Field Values
(Results will appear below.)
Results for date: 2009.643798828125
Declination = 12.604° changing by -0.09 °/year
Inclination = 58.587° changing by -0.004 °/year
X component = 24,156.84 changing by -27.01 nT/year
Y component = 5,401.57 changing by -45.68 nT/year
Z component = 40,531.6 changing by -65.36 nT/year
Horizontal Intensity = 24,753.38 changing by -36.3 nT/year
Total Intensity = 47,492.53 changing by -74.7 nT/year

However, the inclination and declination must be changed to radians before inputting to the unit (multiply them by PI / 180). For the example data above, the inclination would be 1.022 radians, declination 0.2199 radians.

The reference vector can be derived from the inclination and declination, or from the information above. However, the CHIMU requires a unit vector, so the information above must be normalized. For the example data above:
X = 24156.84 / sqrt (24156.84^2 + 5401.57^2 + 40531.6^2) = 0.5086

Likewise, the entire reference vector would be: (0.5086, 0.1138, 0.8534).

5.2.16 SOFTWARE RESET (ID 0x0F)

Description	**Software Reset**
ID	**0x0F**
Length	**1**
Type	Input Message
Comment	**Performs a soft reset of the unit**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	1	*id* or 0xAA	0x0F	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Reset	-	If package = 0xAB, the unit will perform a software reset. All non-flash saved settings will be cleared to defaults.

This message will force a soft reset of the unit.

5.2.17 UART SETTINGS (ID 0x10)

Description	**UART SETTINGS**
ID	**0x10**
Length	**6**
Type	Input Message
Comment	**Allows setting of UART rate and message mask**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	6	*id* or 0xAA	0x10	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Rate	-	0 = 1 Hz 1 = 5 Hz 2 = 10 Hz 3 = 20 Hz 4 = 25 Hz 5 = 50 Hz 6 = 100Hz*
1	X2	-	Mask	-	Mask of bits for entire output message structure. See below for more information
3	U1	-	Reserved	-	
4	U1	-	Reserved	-	
5	U1	-	Clear / write / save to flash	-	0x00 = Clear all settings from flash 0x01 = write settings until next power up 0xAB = will write and save to flash.

* 100 Hz output rate is not supported at this time. Future reserved.

The CHIMU UART baud rate is currently fixed at 115kbaud. However, the output rate and message selection can be changed to help users with integrating the unit into their system.

Message Mask:

All messages may be turned off if desired thru use of a message mask. This mask enables or disables the ability of the unit to output certain messages. The mask should typically only be used to turn output messages 0x01, 0x02, 0x03, 0x07 on or off. These are the messages output from the unit during normal operation.

The mask bits correspond to the output message id numbers. So message 0x01 (Raw Output) is bit 1, message 0x02 is bit 2, etc.

The default is no mask (all on) or 0xFFFF.

The mask to turn off message 0x01 is: 0xFFFD

The mask to turn off message 0x01, 0x02, and 0x07 is: 0xFF79

UART Recommendations:

The maximum rate on the UART bus is 50Hz. At 50Hz, it is recommended that a mask be applied to turn off all messages except the Attitude (0x03) message to reduce data processing by the host processor. The Attitude message contains attitude information as well as attitude rate information which typically necessary for control of a vehicle.

For 200 Hz data output, implement the SPI bus.

UART Method for Low Rate Queries

If polling only approach to using the unit is to be taken, the user should set the update rate to the maximum 50Hz rate and use the “Ping” command to request individual messages. In this case, the CHIMU will respond within 20 milliseconds to a received request. This method is not recommended for high rate data output.

5.2.18 RESERVED (ID 0x11)

Description	**RESERVED**
ID	**0x11**
Length	**N/A**
Type	Input Message
Comment	**DO NOT USE THIS MESSAGE ID**

Do not send message ID 0x11. This is a reserved factory message capability for the unit.

5.2.19 USER PIN OPTION SET (ID 0x12)

Description	**User Pin Option Select**
ID	**0x12**
Length	**6**
Type	Input Message
Comment	**Allows user to define what action pin 20 performs when pulled low. Version 1.4 SW and above only.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	6	*id* or 0xAA	0x12	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Option Select	-	See below
1	U1	-	Spare1	-	
2	U1	-	Spare2	-	
3	U1	-	Spare3	-	
4	U1	-	Spare4	-	
5	U1	-	Read / write / save to flash Also: Disable and clear pin flash settings completely	-	0x00 = Read current settings via output message ID 10. 0x01 = write settings and use pin until next power up 0x02 = will write and save to flash. 0x03 = clears any settings from flash

Option Select –

Option Select Value	**Function when Pin 20 is pulled low**	**Function when Pin 20 is allowed to go high**
0x00	No functions	No functions
0x01	UART 1 is disabled and CHIMU pins are changed to open drain pins. This is useful when used with the Monkey unit for example, and CHIMU com is handled via SPI bus. It frees up the serial port on the Monkey platform for other functions.	UART 1 is enabled
0x02 – 0xFF	None at this time	None at this time

5.2.20 GPS / Substituted Heading Replacement (ID 0x13)

Description	**Internal Heading Replacement**
ID	**0x13**
Length	**5**
Type	Input Message
Comment	**Allows user (when in Euler estimator) to replace magnetometer data heading with GPS velocity heading. Version 1.4 SW and above only.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	5	*id* or 0xAA	0x13	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Enable / Disable	-	0x00 = Do not use / disabled 0x01 = Use value
1	R4	-	GPS Heading	degrees	

This option is only valid when using the Euler estimator.

In high magnetic environments (high current, ferrous metal, etc), the magnetometer solution may become corrupted or invalid.

This message allows the user to replace the yaw correction within the CHIMU filters that is typically performed using the magnetometers with GPS heading. This input value represents the actual heading of the unit, typically returned from a GPS unit as “Course over Ground” or similar.

An update is sent with the first field (“enable / disable”) set to “1”. The last value associated with a valid “use value” field is maintained until either a new update is provided or an update disabling the feature is sent. Because of this, high rate repetition of stale data is not needed.

Note that heading is in degrees, not radians to make it easier to interface to other systems.

Do not send updates faster than 5 Hz.

6. Output Message Details

Shown in this section are the specific message descriptions for output messages from the unit.

6.1 Fixed Message Output

The current message set is fixed with respect to mode. All messages for a given mode are output at a fixed rate (default is 25 Hz) unless altered by the UART settings mask. The modes and messages in that mode are as follows:

Table 4. Default Messages Output Per Mode

Mode	Messages	Single Message or Persistent?
INIT	Ping (0x00) Bias and Scale Factor (0x04)	Single Single
RUNNING	Scaled sensor values (0x02) Attitude (0x03) Gyro Bias (0x07) Raw values (0x01)	Persistent Persistent Persistent Persistent
ACCEL CAL	Scaled sensor values (0x02)	Persistent
MAG CAL	Mag Cal (0x06) Bias and Scale Factor (0x04)	Persistent Persistent
SF Check	SF Check (0x0F)	Persistent
TEMP CAL	Temp Cal (0x08)	Persistent

6.2 Output Messages

The output messages from the unit are shown in this summary table:

Table 5. CHIMU Message Output

Name	ID	Length	Description
Ping	0	5	"I'm alive" message with software version number
IMU Raw	1	22	Raw counts from sensors
IMU FP	2	48	Floating point values
Attitude	3	59	Attitude data, including bit that indicates quaternion or Euler output is prime
Bias and Scale Factor	4	66	Bias and Scale Factor for all sensor channels
Mode / BIT	5	2	Indicates active mode
Magnetometer Cal	6	12	Magnetometer calibration data
Gyro Bias	7	12	Rate sensor biases calculated by estimator
Temperature Cal Data	8	35	Output during temperature calibration showing data results
DAC Offsets	9		
User Pin Select Option	10	6	Returns settings for user pin select options
RESERVED	11 – 13		Reserved for future messages
Mag Ref Vector	14	20	Current magnetic reference stored on unit
Scale Factor Check	15	12	Allows check of rate sensor scale factor

Note: The length shown in this section is the package / payload length for that message. It does not include the header characters (0xAEAE), length byte, device ID byte, message ID byte, or checksum byte.

6.2.1 PING (ID 0)

Description	**Ping**
ID	**0**
Length	**5**
Type	Output Message
Comment	**"I'm alive" kind of message, sent during boot and at request of user, has an identifiable ASCII character (!) that allows use of a terminal program to verify UART is active.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	3	(U1)	0	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	I'm Alive	-	0x23 – Exclamation point character
1	U1	-	SW Major	-	Major software version identifier
2	U1	-	SW Minor	-	Minor software version identifier
3	U2	-	Unit Serial Number	-	Factory loaded serial number

This message appears on boot and at request (via ping request input message). It responds with "!" and the byte values for the onboard software major and minor values.

6.2.2 IMU RAW (ID 1)

Description	**Raw sensor data**
ID	**1**
Length	**22**
Type	Output Message
Comment	**Raw sensor data output, no scale factors or biases applied. Useful for education or external filter development. No calibrations are applied to this data; it is simply raw ADC counts.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	22	(U1)	1	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U2	-	CPU Temp	-	Internal CPU temp ADC counts
2	U2	-	ACC X	-	Accelerometer X raw counts
4	U2	-	ACC Y	-	Accelerometer Y raw counts
6	U2	-	ACC Z	-	Accelerometer Z raw counts
8	I2	-	MAG X	-	Magnetometer X raw counts
10	I2	-	MAG Y	-	Magnetometer Y raw counts
12	I2	-	MAG Z	-	Magnetometer Z raw counts
14	U2	-	RATE X	-	Gyro X raw counts
16	U2	-	RATE Y	-	Gyro Y raw counts
18	U2	-	RATE Z	-	Gyro Z raw counts
20	U2	-	SPARE 1	-	ANA1 ADC read

6.2.3 IMU FP (ID 2)

Description	**Floating point IMU sensor data**
ID	**2**
Length	**48**
Type	Output Message
Comment	**Scaled, bias removed data based on attitude estimator calculations.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	48	(U1)	2	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	R4	-	CPU Temp	°C	Internal CPU temperature
4	R4	-	ACC X	m/s^2	Accel X
8	R4	-	ACC Y	m/s^2	Accel Y
12	R4	-	ACC Z	m/s^2	Accel Z
16	R4	-	RATE X	rad/s	Gyro X
20	R4	-	RATE Y	rad/s	Gyro Y
24	R4	-	RATE Z	rad/s	Gyro Z
28	R4	-	MAG X	Gauss	Magnetic X
32	R4	-	MAG Y	Gauss	Magnetic Y
36	R4	-	MAG Z	Gauss	Magnetic Z
40	R4	-	SPARE 1	-	ANA1 ADC read
44	U4	0.005	Time	sec	Time since turn on (internal CPU timer)

6.2.4 Attitude (ID 3)

Description	**Attitude and Heading estimates**
ID	**3**
Length	**59**
Type	Output Message
Comment	**Contains Euler and Quaternion estimates of current attitude.** **IMPORTANT:** **Estimator choice defines which set of data (Euler, Quaternion) is valid!**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	59	(U1)	3	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	R4	-	PHI	rad	Roll angle
4	R4	-	THETA	rad	Pitch angle
8	R4	-	PSI	rad	Yaw angle (Reported True North if reference vector has been applied, else magnetic north)
12	R4	-	Phi Dot	rad/s	Roll angle rate (identical to scaled sensor value)
16	R4	-	Theta Dot	rad/s	Pitch angle rate
20	R4	-	Psi Dot	rad/s	Yaw angle rate
24	R4	-	q_0	-	Quaternion (scalar)
28	R4	-	q_1	-	Quaternion x
32	R4	-	q_2	-	Quaternion y
36	R4	-	q_3	-	Quaternion z
40	R4	-	$q_{0\ dot}$	-	Rotation rate quaternion
44	R4	-	$q_{1\ dot}$	-	
48	R4	-	$q_{2\ dot}$	-	
52	R4	-	$q_{3\ dot}$	-	
56	X1	-	Calibration Status	-	See below for breakdown of calibration status byte
57	X1	-	Built In Test (BIT)	-	See below for breakdown of BIT status byte
58	X1	-	Configuration Info	-	See below for breakdown of Config Info status byte

The calibration status byte is a bit field reflecting the state of the unit's internal calibration. Shown below is the interpretation of this byte:

Calibration Status bit fields:

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
X	Custom UART	Gyro Bias Saved	DAC offsets set	Magnetic reference information set	Temperature calibrated rate sensors	Magnetometers calibrated	Accelerometers calibrated

1 = TRUE, 0 = FALSE

Description of the bits is self explanatory by their titles except for bit 6. This bit indicates special UART settings have been saved to flash memory.

For basic operation, magnetometers and accelerometers must be calibrated. For precise operation, magnetic reference information must also be set. For faster startup and temperature insensitive operation, the temperature calibration bit needs to be completed. The DAC offsets are an added feature, and do not affect estimate operation.

The built in test (BIT) status byte is a bit field reflecting the error state of the unit. Shown below is the interpretation of this byte:

BIT Status bit fields:

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
X	I2C BUS FAIL	WATCHDOG TIMER RESTART	TEMP CAL READY FAIL	CAL FAIL	UART FAIL	SINGULARITY FAIL	MAG SATURATION

1 = TRUE, 0 = FALSE

These bits require some more discussion:

1) **Magnetic Saturation BIT** – If the magnetometers saturate, this bit will be set. It is cleared after one reporting message (i.e. non latching BIT)
2) **Singularity BIT** – If a singularity condition in the attitude estimate occurs, this bit will be set to indicate a degraded estimate may be being output
3) **UART BIT** – If set, there was a buffer overrun or improper message sent to the unit. It is cleared after one reporting message (i.e. non latching BIT)
4) **Calibration BIT** – If there is a failure to complete a calibration process that could leave bad results in flash memory, this bit is set.
5) **Temperature Calibration Ready BIT** – Set when Temperature Calibration is in progress and if there are no results to allow temperature calibration yet. If the temperature calibration process is started at too high a temperature to allow enough data points, this bit will never clear. If it does clear, the temperature calibration was successful enough to establish new values into flash memory and the process can be stopped.
6) **Watchdog Timer Restart** – Indicates that the unit has had to recover from a locked condition and its watchdog timer was engaged to reset the unit. This BIT is typically flagged on start,

as a power down of the system can erroneously set this bit. Powered, in run operation of the unit should not see this bit flagged. Check all inputs if it is flagged after startup.

7) **I2C BUS Fail** – The internal I2C bus can get locked by devices on the chip under some circumstances. In most situations, the bus is cleared and reset in less than 50 milliseconds. If this occurs, however, this bit is set to indicate the problem.

The configuration information status byte is a bit field reflecting the configuration state of the unit. Shown below is the interpretation of this byte:

Configuration Info Status bit fields:

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
Allow Hardware Pin Config Override	SW Centripetal Velocity Active	Estimator Type	TBD	Rate / Angle Out Configuration	Temp calibration active	HW Centripetal Velocity Active	SPI Enabled

1 = TRUE, 0 = FALSE

These bits require some more discussion:

- Hardware Pin Configuration Override – If this bit is set (default), then the hardware pins for centripetal velocity, temperature calibration, and SPI enabling are active. The configuration can be changed by the status of these pins at boot. This can be disabled thru use of the configuration set message.
- SW Centripetal Velocity Active – set when software velocity messages are being sent and used
- Estimator type – 0 = Euler estimator, 1 = Quaternion estimator
- TBD bit is reserved for future use
- Rate / Angle out – 0 = angle output on DAC channels, 1 = rate output on DAC channels
- Temp calibration active – 0 = false, 1 = true
- HW Centripetal Velocity Active – set when hardware channel is being used for forward velocity input. Represents status of hardware enable pin, but can be prevented if configured to ignore this pin.
- SPI Enabled – 0 = false, 1 = true

6.2.5 Bias and Scale Factor (ID 4)

Description	**Bias and Scale Factor**
ID	**4**
Length	**66**
Type	Output Message
Comment	**Outputs bias and scale factor for all sensors**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	66	(U1)	4	See Below	NONE

Byte offset	Number format	Scaling	Name	Units	Description
0	I2	-	Temp Sensor Bias	-	Do not change
2,4,6	I2 * 3	-	Accel X, Y, Z bias	m/s^2	Note: 3 integers, one for each axis
8,10,12	I2 * 3	-	Rate Sensor bias	Rad/s	""
14, 16, 18	I2 * 3	-	Magnetometer bias	Local gauss (normalized)	""
20	I2	-	Hardware analog 1 read (velocity input) bias		
22	R4		Temp Sensor SF	-	
26,30,34	R4 * 3	-	Accel X, Y, Z SF	m/s^2	Note: 3 floating point values, one for each axis
38,42,46	R4 * 3	-	Rate Sensor SF	Rad/s	""
50,54,58	R4 * 3	-	Magnetometer SF	Local gauss (normalized)	""
62	R4	-	Hardware analog 1 read (velocity input) SF		Scale as needed for external hardware speed input.

This message is output during magnetometer calibration automatically, and at request typically. Boot values for the rate sensors in this message will typically be zero as it is output before calculation. Therefore, requesting this message after run mode has been entered is the best method for obtaining the full correct set of data if needed.

6.2.6 Mode / BIT (ID 5)

Description				**Mode indicator and BIT results**		
ID				**5**		
Length				**2**		
Type				Output Message		
Comment				**Output only when mode changes**		
Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	2	(U1)	5	See Below	XSUM
Byte offset	Number format	Scaling		Name	Units	Description
0	U1	-		Mode	-	Mode: 0 – INIT/BOOT 1 – RUNNING 2 – ACC CAL 3 – MAG CAL 4 – SF CHECK 5 – TEMP CAL
1	U1	-		BIT	-	BIT decoded per description below

The BIT message can be decoded per Message 3, as they are identical.

6.2.7 MAG CAL (ID 6)

Description	**Magnetometer calibration values**
ID	**6**
Length	**12**
Type	Output Message
Comment	**Output during magnetometer calibration only.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	12	(U1)	6	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	I2	-	MagXmin	gauss	Min x axis magnetic value during cal
2	I2	-	MagYmin	gauss	Min y axis magnetic value during cal
4	I2	-	MagZmin	gauss	Min z axis magnetic value during cal
6	I2	-	MagXmax	gauss	Max x axis magnetic value during cal
8	I2	-	MagYmax	gauss	Max y axis magnetic value during cal
10	I2	-	MagZmax	gauss	Max z axis magnetic value during cal

This message shows the current magnetometer raw values during a magnetometer calibration. It can be useful to display these values during calibration to highlight sensitive magnetic north calibration.

6.2.8 GYRO BIASES (ID 7)

Description	**Gyro Bias Values**
ID	**7**
Length	**12**
Type	Output Message
Comment	**Provides running calculated biases for rate sensors**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	12	(U1)	7	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	R4	-	Rate X bias	rad/s	X gyro bias calculated from internal estimator
4	R4	-	Rate Y bias	rad/s	Y gyro bias calculated from internal estimator
8	R4	-	Rate Z bias	rad/s	Z gyro bias calculated from internal estimator

6.2.9 TEMPERATURE CALIBRATON DATA (ID 8)

Description	**Temperature Calibration Data**
ID	**8**
Length	**35**
Type	Output Message
Comment	**Provides latest temperature calibration statistics during temp cal run**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	35	(U1)	8	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0, 2,4	I2	-	Bias	-	Bias for x,y,z rate sensors based on temperature calibration routine in effect
6,10,14	R4	-	Scale Factor	-	Scale factor for same
18,22,26	R4	-	Correlation Coefficient	-	Figure of merit for correlation of temperature calibration per channel
30	R4	-	Temperature	C	Current temperature
34	U1	-	Data Points	-	Number of temperature points included in calibration (the more the better)

Temperature calibration is done prior to shipment. If you need more from this function, contact us prior to performing please.

6.2.10 DAC OFFSET READ (ID 9)

Description	**DAC OFFSET READ**
ID	**9**
Length	**4**
Type	Output Message
Comment	**Provides offsets stored in flash for output DAC channels**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	4	(U1)	9	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	I2	-	Offset Channel 0	-	DAC Bias for channel 0
2	I2	-	Offset Channel 1	-	DAC Bias for channel 1

DAC offsets are values loaded by the user to modify the output from the DAC channels in rate and angle output modes. Default should be zero for each channel.

6.2.11 USER PIN OPTIONS READ (ID 10)

Description	**User Pin Options Read**
ID	**10**
Length	**8**
Type	Output Message
Comment	**Provide feedback on user pin option**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	8	(U1)	10	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	U1	-	Function select	-	0x00 = Disabled (nothing) 0x01 = Disable UART pins
1	U1	-	Spare1	-	
2	U1	-	Spare2	-	
3	U1	-	Spare3	-	
4	U1	-	Spare4	-	
5	U1	-	Aux 1	-	Factory use only
6	U1	-	Aux 2	-	Factory use only
7	U1	-	Aux 3	-	Factory use only

6.2.12 MAGNETIC REFERENCE VECTOR (ID 14)

Description	**Reports magnetic reference vector unit is using**
ID	**14**
Length	
Type	Output Message
Comment	**Reference vector can and should be changed by user based on location.**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	20	(U1)	14	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0, 4, 8	R4 * 3	-	Mag reference vector (x,y,z)	-	Unit vector describing local magnetic field
12	R4	-	Declination	rad	Local magnetic declination
16	R4	-	Inclination	rad	Local magnetic inclination

This data can and should be tailored for a specific location if accurate heading is desired. Use the magnetic reference vector input message to change and save this information.

6.2.13 RATE SENSOR SF CHECK (ID 15)

Description	**Allows check of rate sensor scale factor**
ID	**15**
Length	**12**
Type	Output Message
Comment	**Outputs integrated rate sensor data if enabled with rate sensor check command**

Message Structure	**Header**	**Length**	**Device ID**	**ID**	**Package**	**Checksum**
	0xAE 0xAE	12	(U1)	7	See Below	XSUM

Byte offset	Number format	Scaling	Name	Units	Description
0	R4	-	Integrated roll angle	rad	Roll rate sensor integrated from start of mode entry
4	R4	-	Integrated pitch angle	rad	Pitch rate sensor integrated from start of mode entry
8	R4	-	Integrated yaw angle	rad	Yaw rate sensor integrated from start of mode entry

7. Software Reprogramming

The CHIMU board can be reprogrammed in the field if necessary. A separate programming package must be used to successfully reprogram the unit, and access to power, ground, and pins 22 and 23 are required. Please contact us for more details.

8. Appendix A: Quaternion vs. Euler Estimator

For dynamic situations where 3D rotations are expected to occur (rockets, tumbling vehicles, etc.), the quaternion estimator is the best choice.

Stable implementations that will not spend significant time pointed at +/- 90 degree pitch orientation may use the Euler formulation as well.

In Quaternion mode (the default), only quaternion and quaternion rate outputs occur. To transform these into standard Euler angles, it is recommended to use the following transformation pseudo code.

```
Sub Get_Euler_From_Quat(&v As EULER_STRUCT, &q As QUATERNION_STRUCT)
{
        float x, sqw,sqx,sqy,sqz,norm;
        sqw = q.w * q.w;
         sqx = q.x * q.x;
         sqy = q.y * q.y;
         sqz = q.z * q.z;
         norm = sqrt(sqw + sqx + sqy + sqz);

         //Normalize the quat
         q.w = q.w / norm;
         q.x = q.x / norm;
         q.y = q.y / norm;
         q.z = q.z / norm;

         v.phi =atan2(2.0 * (q.w * q.x + q.y * q.z), (1 - 2 * (sqx + sqy)));
         If (v.phi < 0) Then v.phi = v.phi + 2 *PI;
         x = ((2.0 * (q.w * q.y - q.z * q.x)));
        //Below needed in event normalization not done
             If (x > 1.0) x = 1.0;
             If (x < -1.0) x = -1.0;
        //
        If ((q.x * q.y + q.z * q.w) = 0.5) {
             v.theta = 2 *atan2(q.x, q.w);
        }elseif{
            ((q.x * q.y + q.z * q.w) = -0.5) Then
             v.theta = -2 *atan2(q.x, q.w);
        }else{
             v.theta = asin(x)
        }
             v.psi = atan2(2.0 * (q.w * q.z + q.x * q.y), (1 - 2 * (sqy + sqz)));
             If (v.psi < 0) Then v.psi = v.psi + (2 * PI);
}
```

9. Appendix B: Temperature Calibration

With no calibration, the unit will snapshot the biases on the rate sensors at power up, assuming that the unit is motionless so that accurate initial bias estimates can be used. If the unit is not temperature calibrated however, then any motion on the unit during power up will result in biases that will affect the solution, usually very dramatically! The CHIMU dynamic estimator is constantly estimating biases for the sensitive components and can remove small initial rates within approximately 30 to 60 seconds.

However, to minimize startup time, the unit should be temperature calibrated. This allows the unit to compute the expected biases based on temperature. This can be done to the unit before shipping, or can be performed by the user to a basic unit.

The calibration process consists of the very basic sequence that follows:

1) Place the unit in a cool environment (i.e. refrigerator or even freezer)
2) Remove the unit from the environment and power it up
3) Using our control software or user software, send the temperature calibration command
    a. Once the calibration command is sent, the unit **MUST REMAIN ABSOLUTELY MOTIONLESS UNTIL CALIBRATION IS COMPLETE!**
4) Once the unit has reported at least 3 temperature snapshots, the unit may be commanded to end calibration.
    a. At least 30 degrees of temperature change from start to finish should be experienced for best results.
    b. We also recommend that you allow the unit to heat up to at least nominal temperature, but preferably the normal operational temperature or above for best results
5) The coefficients are saved to flash memory and are active from this point forward at startup.

For extremely accurate operation at a specific operating temperature, please see the next appendix.

10. Appendix C: Set Point Calibration

Even with temperature calibration, the unit will have to “learn” biases during operation. These are the result of magnetometer or accelerometer calibration inconsistencies that may not be noticeable to the user, as well as inherent changes that can occur in the unit over time.

To obtain the very best operation (i.e. minimal startup time) at a certain operating temperature and environmental conditions, we recommend the following:

1) Perform the temperature calibration prior to this
2) Allow the unit to operate until steady state is achieved on the gyro bias estimates
3) Send message 0x08, Gyro Bias Save, to the unit

The bias values will be saved to flash memory and will be used on every power up after this.

These values can be cleared from flash if the desired biases change over time.

We do not recommend using this for most applications. Most applications do not need this and saving these biases may not be the optimal settings for different usage of the unit.